Nomination of the

HIFAR Research Reactor

as a

NATIONAL ENGINEERING LANDMARK

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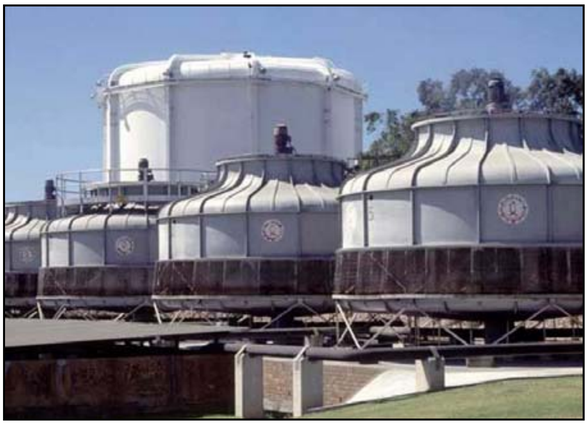
§ This nomination report was substantially prepared by the Australian Nuclear Science and Technology Organisation (ANSTO). Additions have been made by the Sydney Engineering Heritage Committee to bring it into conformity with the plaquing guidelines of Engineering Heritage Australia; the additions are marked with the symbol § at their beginning and end. §

§ Introduction



The High Flux Australian Reactor (HIFAR) was the first nuclear reactor in Australia and will be the only one until its replacement OPAL is commissioned; it was a milestone in Australia's scientific and technological progress.

Following award of a £935,500 contract with UK-based Head Wrightson Processes Ltd in July 1955, construction commenced in February 1956 at the Australian Atomic Energy Commission's research establishment at Lucas Heights, Sydney, and was completed late the following year. The reactor achieved criticality on Australia Day, 1958 and was set in operation by Prime Minister R G Menzies on 18 April. After two years of reactor physics measurements HIFAR began full operations on 20 October 1960.

Since then, HIFAR has provided training for several generations of nuclear engineers and scientists, and has enabled Australia to pioneer many of the applications of nuclear science and technology to industry, medicine and education. Of particular note are the nation-wide distribution of radiopharmaceuticals for nuclear medicine, development of the fission product technetium generator and application of neutron and gamma-based applications to industry.

With over 45 years of full-power operations, HIFAR is testament to the capabilities of its staff and operators who upgraded the reactor to meet developing world practice and changed regulatory practice. HIFAR continues to provide a basis for Australia's ongoing national interest in the peaceful applications of nuclear technology world wide. It has been central to Australia's international nuclear cooperation programs, principally through the International Atomic Energy Agency (IAEA) and will remain so until its replacement the OPAL reactor becomes operational.

Many eminent nuclear engineers and scientists were associated with the establishment of HIFAR, notably Sir Phillip Baxter and Charles Watson-Munro.

The HIFAR Research Reactor is of National significance, historically and technically, and has been of high social benefit to Australia. It has underpinned Australia's achievements in nuclear science and technology. §

Plaque Nomination Form

Name of work: **HIFAR Research Reactor**

The above-mentioned work is nominated to be awarded a **National Engineering Landmark**

Location: **New Illawarra Road, Lucas Heights, NSW 2234**

Owner (name & address): **Australian Nuclear Science and Technology Organisation (ANSTO), PMB 1, Menai, NSW 2234**

The owner has been advised of this nomination, and a letter of agreement is attached.

Access to site: **The HIFAR Research reactor is on the ANSTO site. For access contact ANSTO**

Nominating body or person: **Australian Nuclear Science and Technology Organisation**

Chief of Operations
30/1/06

This plaquing nomination is supported and is recommended for approval.

Glenn Rigden
Chair
Sydney Engineering Heritage Committee
20 February 2006

The Administrator
Engineering Heritage Australia
Engineers Australia
Engineering House
11 National Circuit
BARTON ACT 2600

Australian Government

ansto
Nuclear-based science benefiting all Australians

20 January 2006

Michael Clarke
Engineering Heritage Panel, Engineers Australia
26a Campbell Ave
Normanhurst
NSW 2076

Dear Mr Clarke

ANSTO nominates the research reactor HIFAR as a **NATIONAL ENGINEERING LANDMARK** under the Australian Historic Engineering Plaquing Program of Engineers Australia. The plaquing nomination assessment form for HIFAR is enclosed. ANSTO is owner and operator of HIFAR.

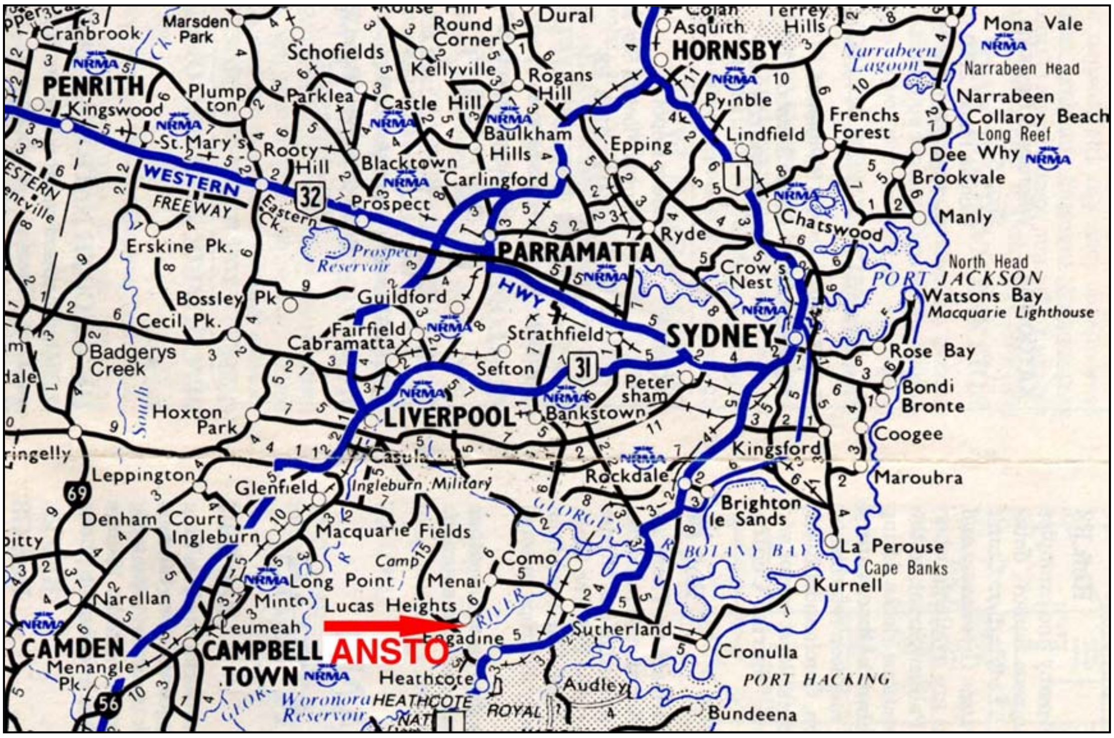
HIFAR is of high historical significance being the first nuclear reactor operated in Australia. HIFAR has underpinned Australia's achievements in nuclear science and technology since achieving routine operation in 1960. With over 45 year of full-power operations, HIFAR has provide training for a generation of nuclear engineers and scientists, and enabled Australia to pioneer many of the applications of nuclear science and technology to industry, medicine and education. Of particular note are the nationwide distribution of radiopharmaceuticals for nuclear medicine, development of the fission product technetium generator and application of neutron and gamma-based applications to industry.

The continuing successful operation of HIFAR is testament to the capabilities of it staff and operators who upgraded the reactor to meet developing world practice and changed regulatory practice. HIFAR continues to provide a basis for Australia's ongoing national interest in the peaceful applications of nuclear technology world wide. It is central to Australia's international nuclear cooperation programs, principally through the International Atomic Energy Agency (IAEA).

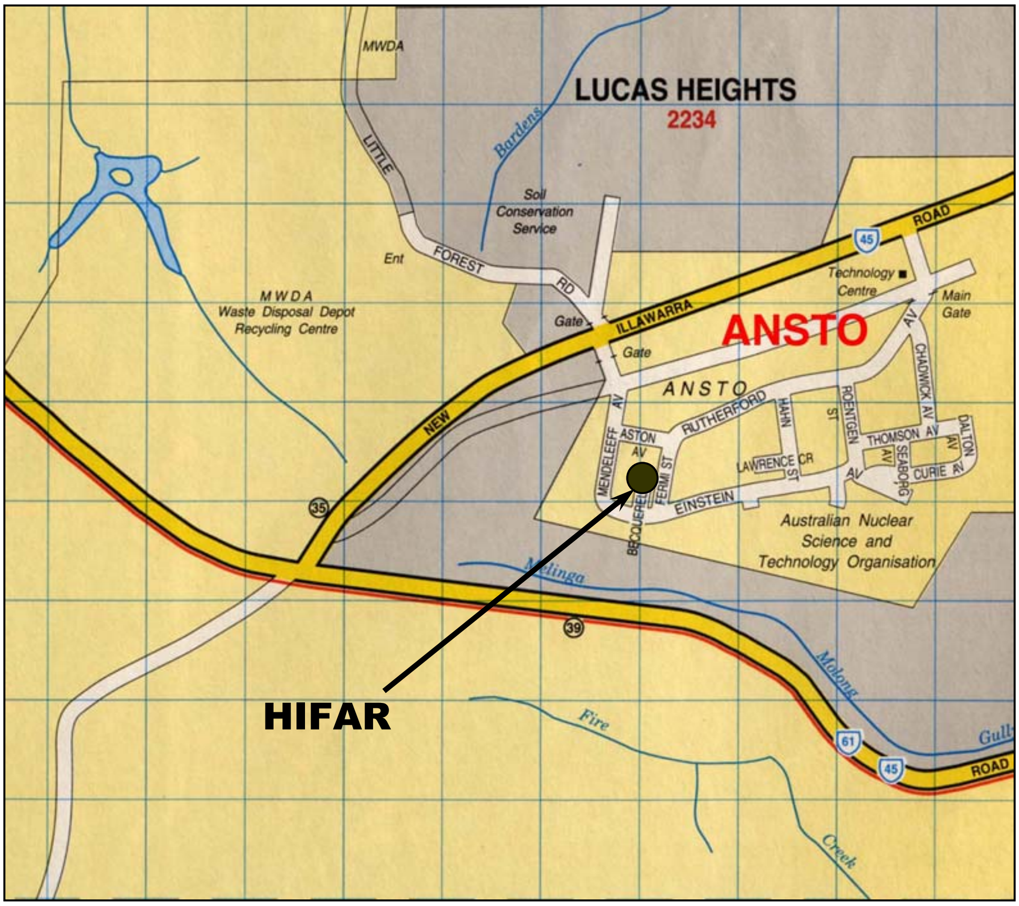
For further information, please contact Dr Kaye Hart on 02 9717 3742 or by email on Kaye.Hart@ansto.gov.au.

Yours sincerely

Dr Ron Cameron,
A/Executive Director



§ **ANSTO Locality Map** §



§ ANSTO Site Map §

PLAQUING NOMINATION ASSESSMENT FORM

1. BASIC DATA:

Item Name: High Flux Australian Reactor (HIFAR)

Other/Former Names: AE443 was used before the name HIFAR was adopted.

Address: New Illawarra Rd
Lucas Heights NSW 2234

Local Government Area: Sutherland Shire

Owner: Australian Nuclear Science and Technology Organisation (ANSTO)

Current use:

- Production of radioisotopes for medicine, industry and research. Isotopes are produced for both the domestic and overseas markets. The value of this production is $20M per annum (ANSTO Annual Report 2003- 2004)
- Provision of irradiation facilities including neutron transmutation doping of high purity silicon for use in the semi-conductor industry;
- Research applications including the use of neutron diffraction techniques for determining the structure of materials. This is a major enterprise focussing on seven major instruments through ANSTO's Bragg Institute[1] and involving extensive collaboration with local universities through AINSE[2] (the Australian Institute for Nuclear Science and Engineering) and with overseas institutions.
- Learning and development programs involving ANSTO staff and research students through AINSE.
- Support of Australia's commitment to the International Atomic Energy Agency (IAEA) through the provision of training facilities, particularly to scientists in the Asia/Pacific region;
- Community education through a formal program of site tours, open days and related initiatives.

Former use (if any): Materials testing and fuel element research and development

Designer:

The HIFAR reactor is a slightly modified version of an original UK design called DIDO, which was, in turn, modelled after the CP5 reactor built near Chicago. Three examples of the DIDO class reactor and another three of a variant called PLUTO were built. Three of the reactors were located in the UK (DIDO, PLUTO and DMTR [PLUTO class]), one in Denmark (DR3 [PLUTO class]), one in Germany (FRJ-2 [DIDO class]) and one in Australia (HIFAR [DIDO class]).

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[1] www.ansto.gov.au/ansto/bragg/index
[2] AINSE is a joint venture between ANSTO, 36 Australian universities, two New Zealand universities and one New Zealand crown research institute (www.ansto.gov.au/ainse/index).

The UK Atomic Energy Authority provided the Australian Atomic Energy Commission (AAEC) with plans and specifications of DIDO. The AAEC modified the original design following early operational experience with DIDO, which first went critical in November 1956.

Maker/Builder:

The contract to the value of £A937,500 was let on 7 July 1955 to the UK company Head Wrightson Processes Ltd for the construction of a research reactor based on the UKAEA DIDO design. The contract price did not include the steel containment housing. In addition, separate contracts were let to the UKAEA for the fuel elements and to the US Atomic Energy Commission for the supply of heavy water (deuterium oxide).[3]

Construction was through Head Wrightson Processes of London with International Combustion (Aust) as the main sub-contractor. The associated buildings and services were erected by Hutcherson Bros as the main contractors to the consulting architects, Stephenson and Turner.

Year started:

Construction commenced in 1956 and was completed in 1957 **(Figures 1 and 2)**. HIFAR was brought to criticality at 11:15 pm on Australia Day 26 January 1958 with 11 of the maximum 25 fuel elements in place.

The Research Establishment was formally opened and the reactor was set in operation, by the Prime Minister Rt Hon R G Menzies on 18 April 1958 **(Figures 3 and 3a)**. There was a two year program of reactor physics measurements prior to routine full power at 10 MW operations which was commenced on 20 October 1960.

Physical description and design:

The HIFAR research reactor was designed to provide a large source of high neutron flux over a substantial volume, with relatively easy access for irradiating target materials and several neutron beams suitable for neutron diffraction experiments. By using highly enriched uranium-235 as fuel, heavy water as moderator and reflector surrounded by graphite, a large region of high to medium level thermal neutron flux was achieved at a relatively low power level. At a thermal power of 10 MW, the peak thermal neutron flux in the centre core region is 1.4×10^{14} neutrons/cm^2 sec.

The twenty five fuel elements are located in a cylindrical aluminium tank of heavy water at atmospheric pressure (**Figure 4 and 5**). The original Mark II fuel elements consisted of 10 parallel plates in a box array, with cooling channels between the plates. Each plate consisted of a sandwich of three metallurgically bonded laminations: the centre lamination was an aluminium-uranium alloy and the outer laminations were pure aluminium sheet. In the original fuel elements, the uranium was enriched to 93% in ^{235}U.

The design of the fuel elements was modified over the years to enhance irradiation capability and reactor operation and the level of enrichment has been progressively reduced to less than 20% (low enriched uranium). In the current Mark IV fuel element, introduced in 1970, the uranium is incorporated as a uranium/aluminium

[3] Clarence Hardy *Atomic Rise and Fall – The Australian Atomic Energy Commission 1953-1987*, 1999 Glen Haven, ISBN 0 9586303 0 5

alloy laminate in four inner concentric tubes surrounded by an unfuelled aluminium outer tube. HIFAR uses approximately 30 elements each year.

In the primary circuit, heavy water flows through each fuel element using submersible pumps and heat is transferred to heat exchangers located directly under the main reactor aluminium tank. The primary cooling circuit contains 10 tonnes of heavy water. In the secondary cooling circuit, ordinary water flows through the secondary side of the heat exchangers to cooling towers, where the secondary water is cooled by evaporative cooling.

The number of neutrons in the core is controlled by six cadmium blades, called coarse control arms. The cadmium is a neutron absorber. The coarse control arms are clad in stainless steel and move like semaphore arms in opposing banks of three within the array of 25 fuel elements. As originally designed, HIFAR had a supplementary shutdown mechanism that lowered the level of heavy water in the reactor tank by 600 mm, which reduced reactivity by increasing neutron leakage. Later this supplementary shutdown function was achieved by installation of two vertically operating cadmium safety rods clad with stainless steel.

The reactor aluminium tank is enclosed on its sides and underneath by closely packed graphite blocks which provide space for irradiations in a lower neutron flux. Outside the graphite blocks is a double walled steel tank, known as the thermal shield. The inner surface of the thermal shield is lined with boron to absorb neutrons. The space between the double walls of the thermal shield is filled with lead and also contains copper coils through which water flows to cool the lead. The thermal shield acts as a secondary containment in case of rupture of the reactor aluminium tank, provides additional radiation shielding and operates as a heat sink to prevent excessive heating and hence cracking of the concrete block forming the outermost region of the biological shield. The outer concrete biological shield is constructed of a dense iron shot filled concrete, clad with steel plating in the shape of a right irregular decagonal prism, 6.7 m across the flats. The biological shield reduces radiation levels in the reactor hall to acceptable levels.

Helium gas passes over the free heavy water surface in the reactor tank to remove free deuterium and oxygen produced by the radiolytic decomposition of heavy water.

Experimental facilities provide access to the neutron flux for both neutron beams and irradiation. Horizontal blind tubes that penetrate the shield create neutron beams for experimental use. Some larger horizontal holes are fitted with pneumatic facilities for inserting and removing target materials. The main irradiation facilities of the reactor are provided by way of vertical tubes, some of which were blind and some perforated to enable heavy water to penetrate to cool experiments. Some of these tubes are located outside the reactor core at various distances to access different neutron flux levels. Early in the life of HIFAR, its irradiation capability was vastly enhanced when the changed fuel element design permitted target materials to be loaded inside each fuel element.

The Reactor is at the first floor level inside a containment building. The heat exchangers are located in a heavy water plant room under the reactor (**Figure 6).**

Physical Condition:

The physical condition of HIFAR is excellent. Close control of the heavy water chemistry throughout the life of HIFAR ensured that HIFAR has not suffered from

corrosion problems. Regular maintenance and upgrading of some systems, especially the safety related systems have ensured that the reactor operates at world's best practice.

The key components that affect the useful life of HIFAR are the reactor aluminium tank, the graphite reflector, the reactor steel tank and the cooling coils. The condition of these items has been assessed using engineering investigations, materials inspections and data from the DIDO (UK) reactor which, was shut down in March 1990 on economic grounds. At that time DIDO had generated 190,000 MWd (megawatt days) energy compared with 127,800 for HIFAR by the end of 2005.

The assessment of reactor safety has been an ongoing activity throughout HIFAR's life. This work has been in the vanguard of international efforts to apply advanced assessment procedures, including probabilistic safety studies, developed in the nuclear power industry to research reactors.

On the basis of available evidence, the CEO of the Australian Radiation Protection and Nuclear Science Agency (ARPANSA) licensed ANSTO to operate the reactor to at least December 2006.

Modification and Dates:

Probably the most important modifications were the changes in fuel element design. The original fuel element design known as Mark II were last loaded in 1964. The fuel loading in each Mark II fuel element was gradually increased to enable the enrichment to be lowered from 93% to 80%. The design of the Mark II elements is described above under "Physical Description and Design".

Mark III fuel elements were introduced to increase the irradiation capability of HIFAR. Targets for irradiation could be loaded inside the Mark III fuel element, which was the region of highest neutron flux. The Mark III elements were introduced in July 1959 and used in a mixed core capacity until March 1971. The Mark III design consisted of outer and inner unfuelled concentric tubes with 10 curved fuel plates in a helix pattern, silver brazed in place. The inner open tube of 50 mm diameter permitted the loading of target materials which later could be undertaken even with the reactor operating.

The Mark IV fuel element design replaced the Mark III fuel element design in November 1970 and this design is still in use. The Mark IV fuel element had an outer unfuelled tube and four concentric inner tubes held in place top and bottom by aluminium combs. An emergency core cooling system was installed to force cooling water through holes in the outer unfuelled tube directly onto the fuel plates to ensure there was no reduction in safety from the lower heat transfer capability from the fuelled regions in the Mark IV fuel elements to the heavy water in the reactor aluminium tank. The fuel loading in each fuel element was increased and the enrichment reduced.

There have been two modifications to the reactor tank. The first in 1973 was the installation of flow straighteners in the distribution of flow nozzles. The second in 1975 was an extension of the downcomers to provide a head of water above the fuel tubes for emergency core cooling.

The HIFAR safety systems have been continuously upgraded to comply with new international standards and technical developments.

Various experimental neutron beam facilities have been installed on HIFAR, the most recent being the Australian Small Angle Neutron Scattering Facility (AUSANS).

Historical Notes:

§ The Australian Atomic Energy Commission came into being in 1953 with the objective of making the benefits of the peaceful uses of nuclear energy available to the Australian nation. By arrangement with the British government, the first staff appointed were sent to Harwell in the UK to gain experience in nuclear science[4].

'The AAEC continued to recruit and post its graduate officers to England and by late 1955 there was a team of over 50 there, all but one at Harwell. The team included chemists, chemical engineers, physicists, health physicists, metallurgists, instrumentation and electronics specialists, and engineers. Nearly all were absorbed into existing research and design groups for their on-the-job training, and some became leaders of groups during the next two or three years…

The leaders of the Australian team were appointed early in 1955 and came to Harwell. Both were New Zealanders. The Chief Scientist, Charles Watson-Munro, had been Professor of Physics at Victoria University College, and the Deputy Chief Scientist and Chief Engineer, Dr G.C.J (Cliff) Dalton, was Professor of Mechanical Engineering at Auckland.

Charles Watson-Munro had been in Canada working on Atomic Energy at the end of the war; he took a leading part in building the first reactor there, at the Chalk River Research Establishment, the Zero Energy Experimental Pile called ZEEP, and then went to Harwell and was involved in the building of the first reactor there, the Graphite Low Energy Experimental Pile known as GLEEP.

Cliff Dalton had been a Rhodes Scholar at Oxford, and later had worked at Harwell where he started the first work on Fast Reactors'[5].

Action to start a research establishment in Sydney commenced in 1954. The first major work was to be the building of the High Flux Australian Reactor (HIFAR).

'We were fortunate to obtain the design of this reactor from the UK. Both Watson-Munro and Dalton were convinced from their earlier atomic experiences that a research reactor should have a high neutron flux, particularly if it was required to test reactor materials and produce useful beams of neutrons. The materials testing function requires a neutron flux or intensity as high as possible so that testing of proposed reactor components, including fuel elements, can be carried out in shorter times than the proposed reactor use, otherwise experiments may take too many years to perform.

At that time the same requirements were being met in the UK with the design and construction of a new high neutron flux research reactor at Harwell. Several of the Australian group were already involved in this project, then known by its engineering design number, "E443". Later the reactor was christened "DIDO", and eventually there were five more of its type. The High Flux Australian Reactor (HIFAR) was the second and was followed by a second reactor at Harwell, PLUTO, then one at the Dounreay Research Establishment in the North of Scotland, the Dounreay Materials Testing Reactor (DMTR), and similar reactors at Julich in Germany and Riso in Denmark.

The UKAEA and AAEC agreed that Australia should use this design, and project "AE443" began, following the UK reactor almost exactly a year behind it. This had

[4] http://www.austehc.unimelb.edu.au/tia/794.html#3153

[5] Keith F. Alder: *Australia's Uranium Opportunities* 1996. Self published. ISBN 0 646 29942 5

tremendous benefits for the Australians, as many "teething troubles" were met and overcome, and following on the British experience we were able to save both time and money'[4].

§ The leaders in the research reactor AAEC team at Harwell under Watson-Munro were Bill Roberts and George Page.

'Bill (W.H.) Roberts, senior Engineer, returned to Australia to take charge of construction. Much of the credit for the successful construction & commissioning is due to Bill Roberts. Later he was Operation Manager & Deputy Director at Lucas Heights - he left to become the first Secretary to the Minister for Fuel & Power in Victoria.

George Page, Instrumentation, made substantial modifications while at Harwell and later at Lucas Heights to the design and layout of much of the instrumentation and control equipment. Many of his alterations were fed back into the Dido project. He was a perfectionist with an uncanny perception of possible problems in complex systems. Later he was head of the Technical Physics Section at Lucas Heights and for a while, Deputy Director. He died at a relatively early age in 1967. George was heavily involved in the uranium enrichment project at Oak Ridge during the Manhattan Project - he was an expert on mass spectrographs and ferried and implemented developments from Berkeley (work of Oliphant and Lawrence) to Oak Ridge'[6]. §

'The original site for a research establishment had been selected at the Long Bay rifle range at Maroubra in Sydney, but when the decision was taken to build a large research reactor the present, a more suitable 70 ha site at Lucas Heights was adopted. Work began in October, 1955, with Stephenson and Turner as architects and Hutcherson Bros as main contractors. A contract for a 10 MW heavy water research reactor similar to the DIDO reactor at Harwell was given to the UK firm Head Wrightson Processes Ltd and only minor changes were made to suit the Australian environment. As other laboratories were completed at Lucas Heights, the large team of Australians at Harwell began to return. HIFAR achieved criticality on Australia Day, 1958, and the Research Establishment was officially opened by the Prime Minister (then Mr. R. G. Menzies) on 18 April, 1958'[3] §

Initially HIFAR was operated for materials testing underpinning a nuclear power research program for Australia, the production of increasing quantities of radioisotopes and for the provision of neutrons for research in a number of fields. The reactor underwent a substantial upgrading program in 1982-1988.

The licence issued by the CEO of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) authorises HIFAR to operate until end December 2006.

In 1997 the Australian government agreed to provide funds for ANSTO to build a replacement research reactor at Lucas Heights subject to an acceptable Environmental Impact Statement. ANSTO signed a contract with the Argentine company INVAP S.E. and its Australian alliance partners, John Holland Construction and Engineering Pty Ltd and Evans Deakin Industries Limited for the design, construction and commissioning of the replacement reactor on 13 July 2000. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) issued a licence to construct the reactor on 5 April 2002. Construction of the replacement research reactor, now called

[6] Email 5.2.06 from Keith F Alder to Michael Clarke

the OPAL reactor, is well advanced. It is planned that HIFAR will operate in parallel with OPAL until OPAL performance is confirmed.

Heritage Listings:

A proposal to list HIFAR on the Commonwealth Heritage List was considered by Commonwealth Department of Environment and Heritage. In October 2005, the Minister announced that HIFAR will not be listed because of the need to assure public safety and the costs associated with retaining some parts of HIFAR for heritage purposes.

2. ASSESSMENT OF SIGNIFICANCE

Historic phase:

The construction and operation of the HIFAR research reactor established Australia's credentials as a country operating nuclear plant. The reactor achieved criticality on Australia Day 1958 and on the 18 April of that year, the Research Establishment was opened by the Prime Minister, The Rt Hon R G Menzies CH, QC, MP in a ceremony attended by 900 staff and guests.

HIFAR's early life as a materials testing reactor produced results important to the worldwide programs on the peaceful uses of nuclear energy. Later HIFAR's irradiation capabilities were enhanced, which lead to commercial production of radioisotopes for nuclear medicine, and enhanced neutron beam capabilities for fundamental and applied research on materials.

The successful operation of HIFAR meant that Australia was able to be involved in the peaceful uses of nuclear technology at an early date.

Historic Individuals or Association:

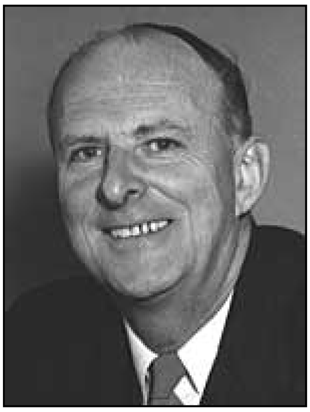
§ HIFAR is associated with a number of eminent nuclear scientists and engineers, notably:

- Sir John Phillip Baxter; and
- Charles Watson-Munro §

§ **Sir John Philip Baxter (1905-1989)** *(See Appendix for detailed biography)*

John Philip Baxter was born on 7 May 1905 in Machynlleth, North Wales.

He became interested in metallurgy and in 1927 graduated in chemistry with first class honours from Birmingham. He transferred to mechanical engineering and completed his Ph.D. in 1928.



Upon graduation he took up a position as Research Engineer at Imperial Chemical Industries Limited (ICI), England, manufacturers of sodium hydroxide. In 1935 he was promoted to Research Manager of ICI General Chemicals, a division which employed 12,000 people.

In 1944 he became Research Director for General Chemicals and at the request of the American Government was seconded by the British Government for three months to Oak Ridge, Tennessee. During a second visit he became involved in the separation of uranium isotopes when the first pure sample of uranium -235 was produced; Oak Ridge made the

material for the Hiroshima atomic bomb.

After the War, Baxter was a consultant on the British post-war Atomic Energy Program and was involved in the construction of facilities at Harwell and Windscale. At the end of 1949he resigned from ICI and left England for Australia.

There, he was appointed Professor of Chemical Engineering at the fledgling NSW University of Technology (later UNSW) and in 1953 Director of the University; the title being changed to that of Vice-Chancellor in 1955. He was Vice-Chancellor until retirement in 1969. His successor Rupert Myers summarized the Baxter years thus: 'History will show Sir Philip Baxter to have been a great educational administrator who built a fine university and made many beneficial changes in the ways universities handled their business and interacted with governments and the community'.

When the Industrial Atomic Energy Policy Committee was established in 1950, Baxter was an obvious choice for its membership. In 1953 he became the Deputy Chairman of the Australian Atomic Energy Commission (AAEC) and in 1957 he became part-time Chairman. Most of the developments in AAEC started as Baxter's ideas.

In 1953 nuclear science and technology were practically non-existent in Australia. Staff were recruited and sent for training to England, mostly to the Atomic Energy Research Establishment at Harwell.

Baxter persuaded the Federal Government that a nuclear reactor was essential for the activities of AAEC and Lucas Heights was eventually selected as the site. He insisted that AAEC carry out original research, the results of which could be traded for the knowledge of others, particularly as there was a good chance of Australia building nuclear power plants. Extensive studies by AAEC indicated that a nuclear power plant in Australia would be economically feasible as uranium was being mined at Rum Jungle in the Northern Territory. The resultant yellowcake was stored at Lucas Heights and proved to be of considerable value to the later processes of uranium enrichment.

In 1954 Baxter and his research team at Harwell decided to center the Lucas Heights Establishment on a high-flux heavy-water-moderated reactor, which became known as HIFAR.

Once the atomic reactor was commissioned, much attention was devoted to the production of radioisotopes, with innumerable types of radioactive substances being produced for medical, industrial and research purposes.

In 1967-68, the Research Establishment had about 1000 staff, including 400 graduates, and an annual budget of 8.5 million dollars.

Baxter, (by now Sir Phillip), became full-time Chairman of AAEC in 1969, when he retired from the UNSW and continued as Chairman until retirement on 15 April 1972.

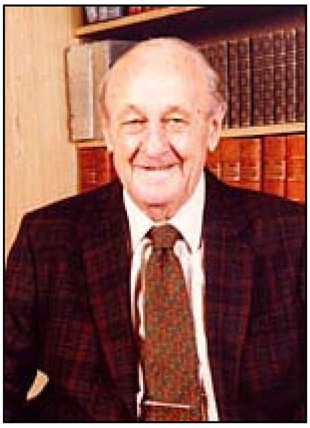
However, unable to completely retire, Sir Phillip became Chairman of the Sydney Opera House Trust in 1969. He remained as part-time and unpaid Chairman through the difficult period following Utzon's resignation in 1966, to the opening of the House in 1973, including completion of construction, staffing and the arranging of performance programs. He retired from the Trust in 1975, on his 70th birthday.

Honours, awards and affiliations

- Knight Commander of the Order of the British Empire, 1965

- Companion of the Order of St. Michael and St. George, 1959
- Officer of the Order of the British Empire, 1945
- Fellow of the Australian Academy of Science, 1954
- Fellow of the Academy of Technological Sciences and Engineering
- Fellow of the Royal Australian Chemical Institute
- Fellow of the Institution of Engineers, Australia
- Member of the Institute of Chemical Engineers
- Fellow of the Royal Society of Arts
- Priestley Research Fellowship, 1925-27
- James Watt Fellowship, 1927-28
- Franklin Metal, 1928
- James N. Kirby Award, 1965 (awarded annually by the Institution of Production Engineers)
- Kernot Medal, 1966 (awarded annually by the University of Melbourne for excellence in engineering) (17)
- Doctor of Laws, *honoris causa* (Montreal), 1958
- Doctor of Science, *honoris causa* (Newcastle, New South Wales, Queensland), 1969
- Doctor of Technology, *honoris causa* (Loughborough), 1969 §

§ **Charles Norman Watson-Munro (1915-1991)** *(See Appendix for detailed biography)*



Charles Norman Watson-Munro was born in Dunedin, New Zealand on 1 August 1915.

He was to make major contributions to science and engineering in four countries. In each country his contribution was at an early stage in the development of a particular technology – radar in New Zealand, nuclear power reactors in Canada and the United Kingdom, and nuclear science and technology in Australia. His contributions in New Zealand and Australia included participation in national committees and as a country representative on international committees.

In 1944 Charles and several other New Zealand scientists were invited to go to Chalk River, Canada, to join a team of Canadian, UK and European scientists undertaking research on the peaceful uses of nuclear energy. Charles' main task at Chalk River was the design of the control equipment for the heavy water reactor ZEEP (Zero Energy Experimental Pile), the first reactor to be built outside the United States.

Early in 1946 a joint UK-New Zealand team, including Charles, commenced work at the newly founded Atomic Energy Research Establishment at Harwell, England, on the design and construction of two graphite moderated natural uranium reactors – BEPO (British Experimental Pile-0) and GLEEP (Graphite Low Energy Pile). Charles was given the responsibility of leading the GLEEP team. Construction began in August 1946 and the reactor went critical on Friday 15 August 1947. The short construction time, in the very difficult conditions that prevailed in England immediately after the end of World War II, was a remarkable achievement and owed much to Charles' skills as a scientist, engineer, and team leader.

In 1955 Charles took up appointment as Chief Scientist with the Australian Atomic Energy Commission (AAEC) focusing attention on the development of an Australian

uranium mining industry and on the initiation of a research and development program. Shortly after his appointment, Charles joined the group of AAEC staff working at Harwell. He returned to Australia in 1957 to take direct charge of the research program and to oversee the completion of the initial set of buildings at the research establishment at Lucas Heights and the final stages of construction of the research reactor, HIFAR.

Charles was the ideal man for the job of AAEC Chief Scientist**.** With the commissioning of HIFAR he became perhaps the only person to be involved in the design, construction and commissioning of the first nuclear reactors in three countries – Canada, the United Kingdom, and Australia. His appointments in those three cases, and the highly successful outcomes, are a testimony to his scientific and technological ability and to his extraordinarily high administrative and management ability.

In 1960, he accepted appointment as Professor of Physics (Thermonuclear) at the University of Sydney where he expended great enthusiasm and energy building up his research group, under Prof. Harry Messel. He spent a year at the University of California, Berkeley and at the end of 1960 introduced a method of plasma preparation for the Sydney experiments that had begun to be studied at Berkeley.

A measure of the subsequent success and standing of Charles and his group was that he was chosen as one of only four people to present invited papers on the state of controlled thermonuclear research worldwide at the Third Atoms for Peace Conference in Geneva.

Towards the end of his career Charles developed an interest in other energy sources, particularly solar energy. He was the prime mover behind the successful work on solar energy that led to the formation of the Department of Applied Physics within the School of Physics.

Degrees and honours

- DSc (Victoria University, New Zealand, 1968).
- OBE (1946).
- Fellow, Institute of Physics (London).
- Fellow, Australian Institute of Physics.
- Fellow, Institution of Engineering (Australia).
- Fellow, Australian Academy of Science (1968). §

Australian Institute of Nuclear Science and Engineering

In 1956, the government agreed to the establishment of the Australian Institute of Nuclear Science and Engineering (AINSE), a Joint Venture between the AAEC and member Universities to promote training and research in nuclear science and technology. The AINSE Council held its inaugural meeting on 4 December 1958. AINSE has provided university access to the capabilities of the HIFAR reactor by researchers and students from member universities, which resulted in many higher research degrees.

Creative or Technical Achievement:

HIFAR has been vital for Australia's achievements in nuclear science and technology which include:

- Neutron beam research;
- Neutron activation analysis;
- Radiation research;

- Applied nuclear physics;
- Materials science and technology;
- Biomedical research and development; and
- Environmental science.
- Reactor safety assessment

In addition HIFAR supports major commercial activities including:

- The production of medical radioisotopes and radiopharmaceuticals;
- Industrial and environmental applications of radioisotopes; and
- The transmutation doping of silicon for use in the semiconductor industry.

The creative achievements of the reactor can be assessed from an analysis of the IAEA International Nuclear Information Systems database. Full details of this analysis are available in *Working paper 3* 'Evaluation of Research Output' in Attachment B of ANSTO's submission to the Research Reactor Review in 1993. For the period 1976 to 1992, the Australian research output in nuclear science and technology represented 1.4 per cent of the world's total, which is comparable to those for other fields found a contemporary survey in the Australian Science and Innovation Impact Brief, *Measures of Science and Innovation* (DITAC,1991)[7]. This survey showed that over a similar period, the Australian contributions to world literature in the fields of chemistry, physics and engineering/technology were 1.4%, 1.2% and 1.7% respectively.

Using the same data, another comparative indicator of Australia's creative output in nuclear science and technology is the number of relevant research documents normalised for population. In **Figure 7**, countries are classified into three groups: a) those with both power and research programs; b) those with research programs alone and c) non-nuclear countries. Not surprisingly, the relative research output of non-power countries lies between those with nuclear power and those without a nuclear reactor. The high Danish output is due in part to the integration of its program into that of the European Union. Australia's output contribution in nuclear science and technology is due in large part to the successful operation and utilisation of the HIFAR reactor over many years.

Research Potential:

HIFAR is scheduled for closing in 2006. The nuclear research program which began on HIFAR will be expanded by the enhanced capabilities of the new OPAL reactor and its new instruments. Details of the current proposals are best reviewed at the website of the Bragg Institute (http://www.ansto.gov.au/ansto/bragg/index.html) and through the links therein.

Social:

HIFAR has made significant contributions to the social development of the Australia through the nationwide provision of nuclear based medical and industrial based products and services. HIFAR was a major scientific instrument and provided educational opportunities and extension services. Operation of HIFAR has been in the national interest. The Australian capability on nuclear issues gained by the successful operation of HIFAR has enabled Australia to participate fully in international discussions on nuclear issues and non-proliferation. These contributions

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[7] Department of Industry, Technology and Commerce, 1991, *Australian Science and Innovation Impact Brief: Measures of Science and Innovation* (Canberra AGPS)

of products, services and support to international participation will continue with the operation of the OPAL reactor.

Rarity:

HIFAR was the first nuclear reactor operating in Australia and it is the only reactor still operating. The only other very much smaller reactors have been Moata (100 kW) and the AAEC Critical Facility (very low power) and both ceased operation many years ago. HIFAR has achieved over 47 years of successful and safe operation. As indicated above, HIFAR is the second of six DIDO class reactors built worldwide, only two of which, FRJ-2 in Germany and HIFAR are still in service.

Integrity/Intactness

HIFAR is currently operating, and will continue to do so until the new OPAL reactor is commissioned. This will ensure continuity of neutron beam, irradiation and radiopharmaceutical services to ANSTO's clients. A decommissioning plan for HIFAR is being developed. ANSTO is committed to decommission HIFAR in line with international best practice.

Statement of Significance

HIFAR is of high historical significance being the first nuclear reactor operated in Australia. HIFAR has historic significance because its design is modelled on the CP5 (Chicago Pile 5) design developed very early in the development of nuclear reactors. The lineage can be traced back to the first reactor CP1 built at the University of Chicago in 1942.

HIFAR has underpinned Australia's achievements in nuclear science and technology since achieving routine operation in 1960. With over 45 year of full-power operations, HIFAR has provided training for a generation of nuclear engineers and scientists, and enabled Australia to pioneer many of the applications of nuclear science and technology to industry, medicine and education. Of particular note were the nationwide distribution of radiopharmaceuticals for nuclear medicine, development of the fission product technetium generator and application of neutron and gamma based applications to industry.

The continuing successful operation of HIFAR is testament to the capabilities of it staff and operators who upgraded the reactor to meet developing world practice and changed regulatory practice. HIFAR continues to provide a basis for Australia's ongoing national interest in the peaceful applications of nuclear technology world wide. It was central to Australia's international nuclear cooperation programs, principally through the International Atomic Energy Agency (IAEA).

§ The HIFAR research reactor has significance under all the heritage criteria of the *NSW Heritage Manual,*

Historically because it was the first nuclear reactor operated in Australia and has been in full-power operations for the peaceful applications of nuclear technology since 1960.

By Association with important scientific organisations, the Australian Institute of Nuclear Science and Engineering, the Australian Atomic Energy Commission and currently ANSTO, and, with many eminent scientists and engineers, of particular technical distinction and leadership qualities being Sir Phillip Baxter the Commissioner in charge, Charles Watson-Munro the Senior Scientist, Bill Roberts,

the senior Engineer in charge of construction and George Page in charge of instrumentation and control.

Creative and Technical Achievement through research and analysis of many aspects of nuclear science that have been acknowledged internationally, combined with study and training programs in Australia and overseas.

Research Potential through existing and planned research programs that can be continued, expanded and enhanced by the new OPAL reactor.

Social is probably the most significant achievement because of the continuous production of radioisotopes for medicine, industry and research; materials testing; use of its irradiation facilities, and community education. All have provided enormous benefits to Australia and worldwide.

Integrity/Intactness measured in broad terms. Highly technical facilities cannot remain pristine but HIFAR has maintained its place in world's best practice through rigorous maintenance, upgradings and special attention to safety. And yet, HIFAR is still readily recognisable as the "same" facility.

Aesthetic assessment can be subjective, however, unlike many large unattractive industrial complexes, the dominant containment building that surrounds HIFAR has received architectural treatment that is aesthetically pleasing. §

Assessed significance: National

§ PROPOSED CITATION

HIFAR RESEARCH REACTOR

The High Flux Australian Reactor - the first nuclear reactor in Australia, achieved criticality on 26th January 1958. It was constructed by and for the Australian Atomic Energy Commission to a modified design of the United Kingdom Atomic Energy Authority by Head Wrightson Processes Ltd, (UK) as primary contractor and International Combustion (Aust), with civil construction by Hutcherson Bros for the architect Stephenson and Turner. Professor Sir John Phillip Baxter was the AAEC Commissioner in Charge, Charles Watson-Munro was the Chief Scientist, the Engineer in Charge was Bill Roberts and instrumentation and control was by George Page. HIFAR enabled Australia to participate internationally in the early development of peaceful uses of nuclear energy and in the application of nuclear science and technology to industry, health, education and research. It has been regularly upgraded to meet developing world and regulatory practice.

The Institution of Engineers Australia

Australian Nuclear Science and Technology Organisation
2006 §

APPENDICES

Images

Figure 1: *Foundations for the HIFAR, 1956*

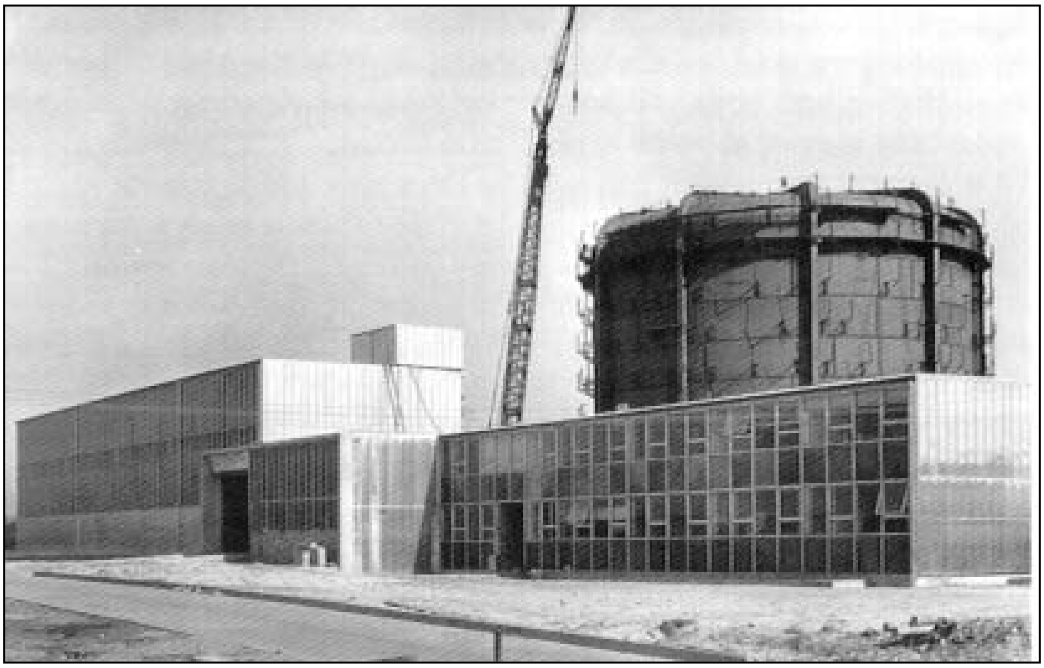


Figure 2: *The Reactor Shell and part of the reactor group of buildings nearing completion, 1957*

Figure 3: *The Prime Minister, the Rt. Hon. R. G. Menzies, C.H., Q.C. M.P. officially opening the Research Establishment and setting HIFAR in operation on 18 April 1958*

§ **Figure 3a:** *Plaque near entrance to HIFAR commemorating opening of Research Establishment and setting HIFAR in operation* §

Figure 4: *View of the reactor top plate when open for maintenance*

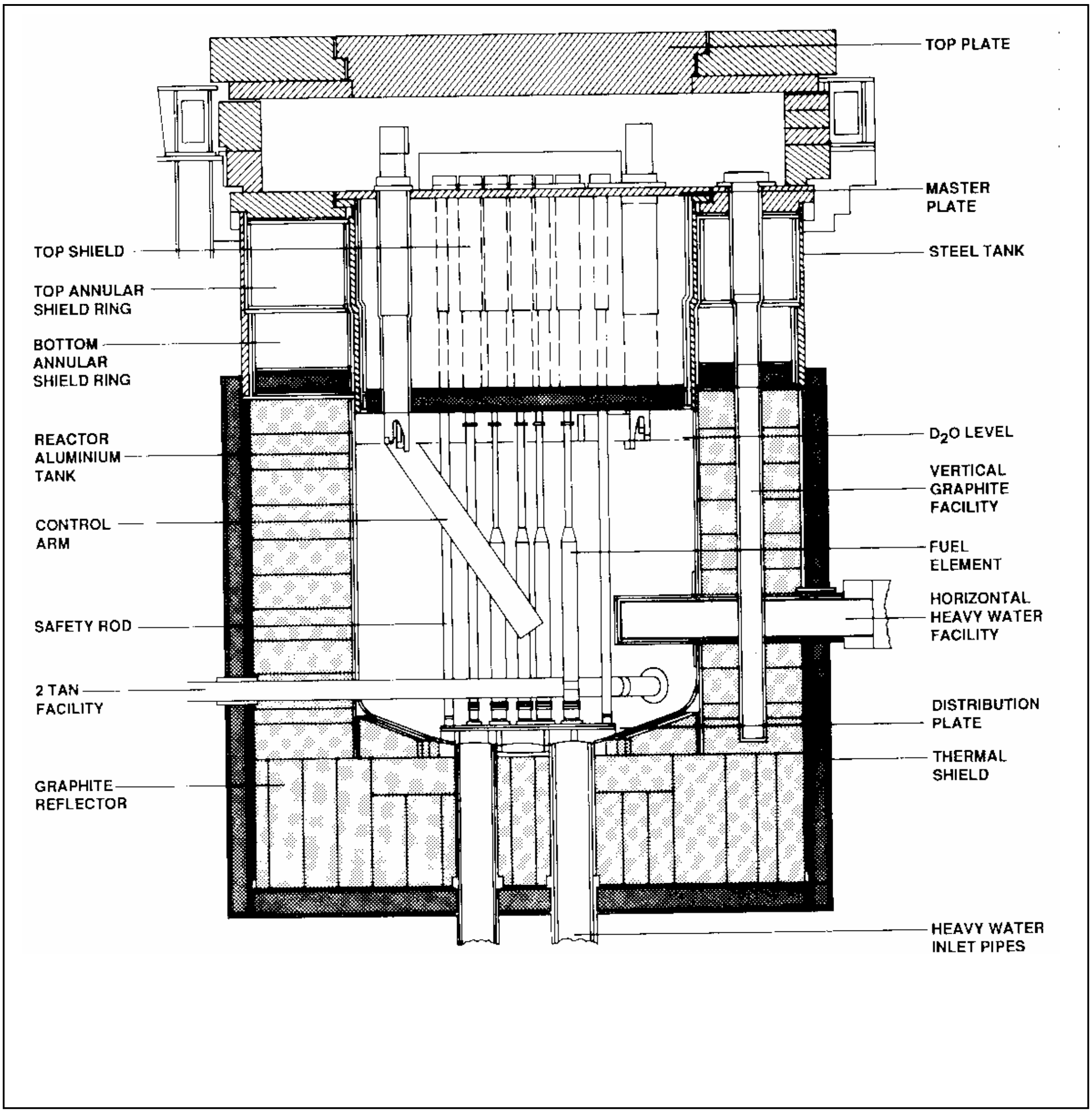


Figure 5: *The configuration of the HIFAR reactor.*

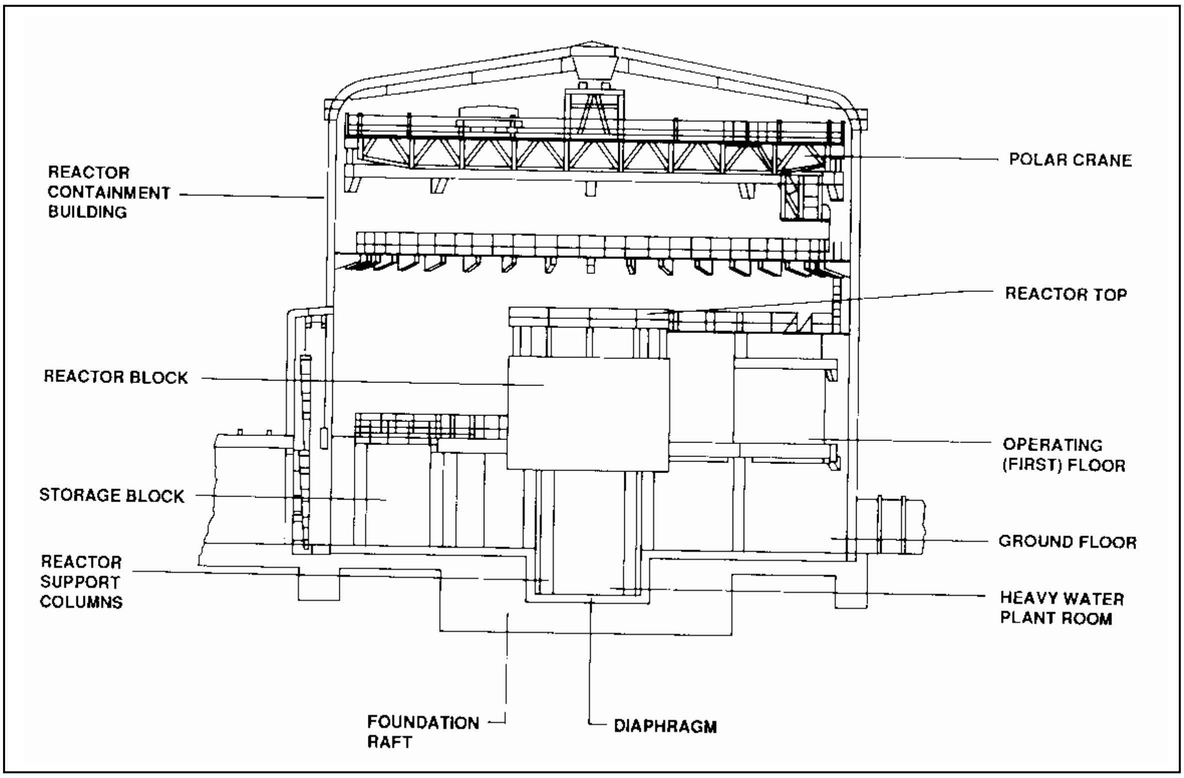


Figure 6: *The location of the HIFAR reactor block within the containment building.*

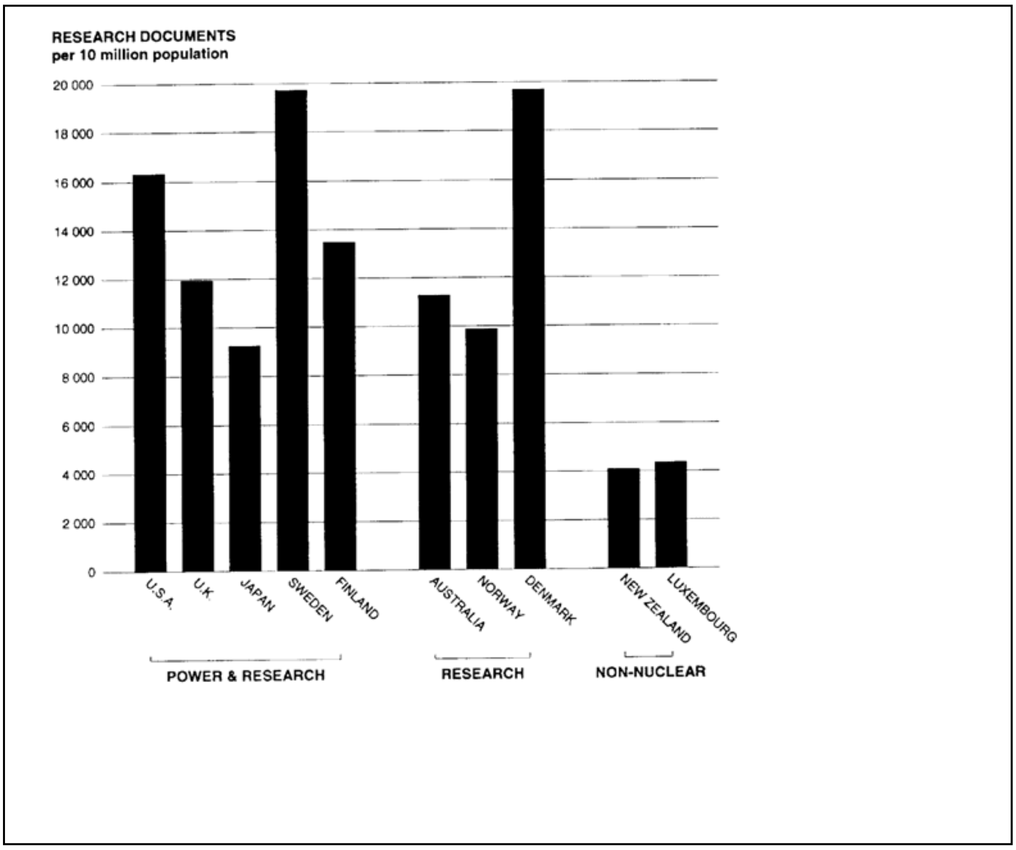
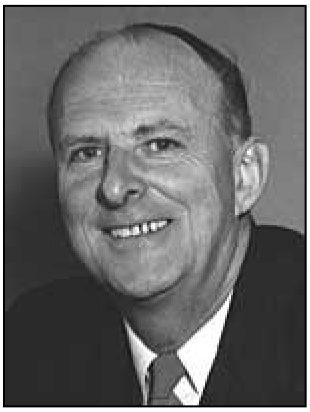


Figure 7: *Nuclear Science and Technology Research Output: Total number of research papers normalised by population (1976-1992). Countries are classified according to whether they have both power and research reactors; research reactors only; or are non-nuclear.*

§ **Sir John Philip Baxter (1905-1989)**



John Philip Baxter was born on 7 May 1905 in Machynlleth, North Wales.

Baxter became interested in metallurgy and in 1927 graduated in chemistry with first class honours from Birmingham. He transferred to mechanical engineering and completed his Ph.D. in 1928.

Imperial Chemical Industries

Upon graduation he took up a position as Research Engineer at Imperial Chemical Industries Limited (ICI) at Billingham in County Durham, where a new factory was being established for the manufacture of sodium hydroxide. In 1935 he was promoted to Research Manager of ICI General Chemicals, a division which employed 12,000 people.

In 1940 Sir James Chadwick, then Lyon Jones Professor of Physics at the University of Liverpool, asked Baxter whether uranium hexafluoride existed and, if it did, could he supply some? As a result of this conversation, ICI supplied a sample of the substance. Later when Chadwick wanted much more, Baxter replied that he could not justify setting up an expensive plant without knowing what the material would be used for. He was then told about the program to construct an atomic bomb. Thus ICI became involved in what was known as the Tube Alloy Project; they supplied 3 kg of uranium hexafluoride to Chadwick, and set up a plant to manufacture a substantial proportion of the uranium hexafluoride for the project.

In 1944 Baxter became Research Director for General Chemicals and at the request of the American Government was seconded by the British Government for three months to Oak Ridge, Tennessee. After completion of the secondment, Baxter was again sent to the States, becoming Deputy Manager of a factory involved in the separation of uranium isotopes that employed 23,000 people; he was there when the first pure sample of uranium -235 was produced. The material for the Hiroshima bomb was made at the factory.

After the War, Baxter resumed his position as Research Director of the General Chemicals Division; he was also a director of Thorium Ltd. and a consultant on the British post-war Atomic Energy Program. He was involved in the construction of facilities at Harwell and Windscale and was directly responsible for some of the research work on separation processes. However, he became restless, was disappointed when ICI withdrew from the production of nuclear energy, was unhappy about the political and economic situation in post-war England, and at the end of 1949 resigned from ICI and left England for Australia.

NSW University of Technology

In 1949 Baxter became Professor of Chemical Engineering at the fledgling NSW University of Technology. In 1952 he was appointed Deputy Director and in 1953 Director of the University; the title being changed to that of Vice-Chancellor in 1955. He remained Vice-Chancellor until his retirement from the University in 1969.

He prodded, coaxed and pushed the new university into rapid growth, both in size and in stature; he supervised the university's move to Kensington. Colleges of the University were established in Newcastle and Wollongong.

In 1959 Baxter established Unisearch Ltd. a wholly owned subsidiary company of the university to offer its experience and facilities to industry and commerce. It was the first organization of this kind in the British Commonwealth.

Amongst his various innovations, Baxter established a School of Nuclear Engineering, firmly believing that Australia should build nuclear power plants. However, after the Government decided not to build one the School was allowed to decline.

In 1958 Baxter put a proposal by the Australian Broadcasting Corporation and the Elizabethan Theatre Trust to the University Council and the National Institute of Dramatic Art (NIDA) was established.

He retired on 30 June 1969. His successor Rupert Myers (later Sir Rupert) succinctly summarized the Baxter years: 'History will show Sir Philip Baxter to have been a great educational administrator who built a fine university and made many beneficial changes in the ways universities handled their business and interacted with governments and the community'.

Australian Atomic Energy Commission

In 1950 the Australian Government established the Industrial Atomic Energy Policy Committee; Baxter was an obvious choice for its membership. His participation was responsible for much of the detail of the Atomic Energy Act which, on 15 April 1953, set up the Australian Atomic Energy Commission (AAEC). The Chairman was Major-General J.E.S. (later Sir Jack) Stevens, formerly Secretary of the Department of Supply and Baxter became its Deputy Chairman. The expert on uranium mining on the Commission was Dr H.G. Raggatt FAA.

Following Steven’s resignation from the AAEC in 1956, Baxter was offered the Chairmanship and declined, but in 1957 became part-time Chairman.

Through his part-time job he left an indelible impression on Australian nuclear activities, which were dominated by his ideas, initiatives and enthusiasm. Most of the developments in AAEC started as Baxter's ideas.

In 1953 nuclear science and technology were practically non-existent in Australia. Staff were recruited and sent for training to England, mostly to the Atomic Energy Research Establishment at Harwell. It was Baxter's influence, with his early connections with atomic energy research in the USA, Canada and the United Kingdom and his close contact with Sir John Cockcroft, Director of the Establishment at Harwell, which led to the necessary security clearances and to the secondment of Australian staff to work as members of the Harwell groups. They were accepted as full working members of the UK team. By 1956 there were about 60 AAEC scientists and engineers working at Harwell, including the Chief Scientist, Charles Watson-Munro (later FAA). AAEC research began at Harwell.

AAEC’s initial plans called for building a small Research Establishment at Long Bay, but Baxter persuaded the Government that a nuclear reactor was essential for the activities of AAEC. After Baxter’s colleagues persuaded him that Long Bay was unwise, Lucas Heights was selected as the site.

In the early nineteen fifties nuclear technology was still the perquisite of a few nations and was shrouded in secrecy. Only members of the 'club' had access even to restricted information. Hence Baxter insisted that AAEC carry out original research, the results of which could be traded for the knowledge of others.

As there was a good chance of Australia building nuclear power plants in the late seventies, the established nuclear reactor systems were studied and teams were sent to Canada and Britain, where they were regarded as equals and were given information freely. Extensive studies by AAEC indicated that a nuclear power plant in Australia would be economically feasible.

During AAEC's early stages there was urgency to mine and extract uranium at Rum Jungle; the mine in the Northern Territory was operated under contract to the AAEC. When the contract expired, Baxter insisted that the mine should continue operation until it exhausted its ore supply. The resultant yellowcake was stored at Lucas Heights and proved to be of considerable value at a later stage.

Baxter realized that it was not good economic policy to sell uranium in its natural state; uranium enriched in the isotope 235 would command a much higher price and could be the basis of an important export industry for Australia. Hence the Research Establishment paid much attention to processes of uranium enrichment.

In 1954 Baxter and his research team at Harwell decided to center the Lucas Heights Establishment on a high-flux heavy-water-moderated reactor. The high-flux reactor erected there was named HIFAR (high-flux Australian reactor).

Once the atomic reactor was installed at Lucas Heights, much attention was devoted to the production of radioisotopes. Some of these cannot be imported from overseas owing to their short lifetimes. From 1960 on, Lucas Heights produced innumerable samples of radioactive substances for medical, industrial and research purposes.

~~At its peak in 1967-68, the Research Establishment had about 1300 staff, including 400 graduates, and an annual budget of 4 million dollars.~~

[In 1967-68, the AAEC had about 1000 staff, including 400 graduates, and an annual budget of 8.5 million dollars]. *(Amended paragraph inserted by ANSTO)*

The high scientific standing of AAEC was recognized when Australia became a Member State and a member of the Board of Governors, when the International Atomic Energy Agency was founded in 1957. The purpose of the Agency was to exploit the uses of atomic energy for the betterment of mankind and to restrict its use for military purposes. Baxter became Australia's representative on the Board and was elected Chairman of the Board of Governors for 1969-1970.

In 1958 Baxter established the Australian Institute of Nuclear Science and Engineering (AINSE), involving all Australian universities, to make the facilities of the Research Establishment available to research workers in the universities and to facilitate contact of the AAEC staff with the universities.

Baxter became full-time Chairman of AAEC in 1969, when he retired from the university. Although he discussed in detail the work of each research worker, he always reported his conversations to the Director of AAEC, Keith F. Alder (General Manager from 1975 to 1982), so as not to create the impression that he was trying to bypass his authority.

Baxter was dedicated to the grand nuclear plan of nuclear science: uranium mining and refining, and nuclear power generation. He had the confidence and support of most of the influential Liberal and Country Party politicians. True, the cost and resources may have been beyond Australia's grasp at that time but Baxter's vision was of a gradual accomplishment, which ultimately would have been of enormous value to Australian science and technology in the 21st century.

Studies of nuclear power plants continued and strong recommendations were forwarded to the Government for one to be erected in Australia. In 1968 Prime Minister J.G. Gorton announced that Australia would build its first nuclear power plant and much preparatory work was carried out on the specifications for the power station. A site was selected at Jervis Bay remote from population and close to plentiful supply of cooling water; preparatory ground works were carried out and an access road was constructed. However, in June 1971 the Government deferred the project. The grounds for this decision were not environmental – in the sixties this was not yet a decisive factor. Prime Minister W. McMahon, still a treasurer at heart, found the expense – between $180 and $207 million dollars – too high. This was the death-knell for Jervis Bay and a heavy blow for Baxter; in July 1972 the project was further deferred and, after Whitlam came to power in December 1972, it was never revived.

Baxter retired from AAEC on 15 April 1972.

Sydney Opera House Trust

In 1961 the Sydney Opera House Trust was established to advise the Government on related policy matters. However, by 1969 action was needed rather than advice, and the Act was amended to make the Trust a smaller body with greatly increased responsibilities. A completely new group of people were appointed to the Trust, and Baxter was appointed Chairman.

The objects and functions of the Trust were, first of all, the administration, care, control, management and maintenance of the Opera House; that is, complete responsibility for everything in, and concerning, this new cultural centre. It was also charged with the provision of facilities for the production of music, opera, ballet, theatre and a number of related activities in the building. Curiously, the objects also included 'promotion of artistic taste and achievement' (in any branches of the arts referred to elsewhere) and 'scientific research into, and the encouragement, of new and improved forms of entertainment and methods of presentation of entertainment'.

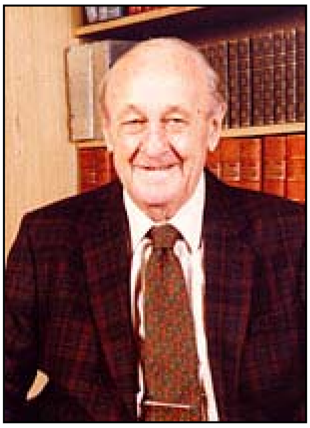
Baxter remained as part-time and unpaid Chairman through the difficult period following Utzon’s resignation in 1966, to the opening of the House in 1973, including completion of construction, staffing and the arranging of performance programs. He retired from the Trust in 1975, on his 70th birthday.

H**onours, awards and affiliations** Knight Commander of the Order of the British Empire, 1965

- Companion of the Order of St. Michael and St. George, 1959
- Officer of the Order of the British Empire, 1945
- Fellow of the Australian Academy of Science, 1954
- Fellow of the Academy of Technological Sciences and Engineering
- Fellow of the Royal Australian Chemical Institute
- Fellow of the Institution of Engineers, Australia
- Member of the Institute of Chemical Engineers
- Fellow of the Royal Society of Arts

- Priestley Research Fellowship, 1925-27
- James Watt Fellowship, 1927-28
- Franklin Metal, 1928
- James N. Kirby Award, 1965 (awarded annually by the Institution of Production Engineers)
- Kernot Medal, 1966 (awarded annually by the University of Melbourne for excellence in engineering) (17)
- Doctor of Laws, *honoris causa* (Montreal), 1958
- Doctor of Science, *honoris causa* (Newcastle, New South Wales, Queensland), 1969
- Doctor of Technology, *honoris causa* (Loughborough), 1969 [8] §

§ **Charles Norman Watson-Munro (1915-1991)**



Charles Norman Watson-Munro was born in Dunedin, New Zealand on 1 August 1915.

The combination of scientific and engineering expertise and his personal qualities enabled Charles to make major contributions to science and engineering in four countries. In each country his contribution was at an early stage in the development of a particular technology – radar in New Zealand, nuclear power reactors in Canada and the United Kingdom, and nuclear science and technology in Australia. His contributions in New Zealand and Australia included participation in national committees and as a country representative on international committees.

In 1944 Charles and several other New Zealand scientists were invited to go to Chalk River, Canada, to join a team of Canadian, UK and European scientists undertaking research on the peaceful uses of nuclear energy. Charles' main task at Chalk River was the design of the control equipment for the heavy water reactor ZEEP (Zero Energy Experimental Pile), the first reactor to be built outside the United States.

Early in 1946 a joint UK-New Zealand team, including Charles, commenced work at the newly founded Atomic Energy Research Establishment at Harwell, England, on the design and construction of two graphite moderated natural uranium reactors – BEPO (British Experimental Pile-0) and GLEEP (Graphite Low Energy Pile). Charles was given the responsibility of leading the GLEEP team. Construction began in August 1946 and the reactor went critical on Friday 15 August 1947. The short construction time, in the very difficult conditions that prevailed in England immediately after the end of World War II, was a remarkable achievement and owed much to Charles' skills as a scientist, engineer, and team leader.

After six years back in New Zealand, in 1955 Charles took up appointment as Chief Scientist with the Australian Atomic Energy Commission (AAEC). In the first few years the AAEC focused its attention on the development of an Australian uranium mining industry and on the initiation of a research and development program. The latter had, as one of its main objectives, the development of a joint R&D program with the United Kingdom (which had already undertaken a vast amount of work on reactor design and on the peaceful applications of nuclear energy, particularly its use

[8] S.J. Angyal: http://www.science.org.au/academy/memoirs/baxter.htm

in electricity generation). Shortly after his appointment, Charles joined the group of Commission staff working at Harwell on the joint program. He returned to Australia in 1957 to take direct charge of the research program and to oversee the completion of the initial set of buildings at the research establishment at Lucas Heights and the final stages of construction of the research reactor, HIFAR (High Flux Australian Reactor). The reactor, which was essentially the same design as the UK reactor, DIDO, went critical on Australia Day, Sunday, 26 January 1958. It proved to be a remarkably successful research tool and also an important source of radioisotopes for use in industry, medical diagnostics and the environment.

The principal objective of the research program in those early days was ‘the development of the means for the economic production of industrial electric power from nuclear fuels’. This was the challenge that attracted Charles to the AAEC; at that time, Australia’s vast coal resources were not widely known. It soon became clear to him that the likelihood of Australia developing a nuclear power industry was remote and, in 1960, he accepted appointment as Professor of Physics (Thermonuclear) at the University of Sydney.

Charles was the ideal man for the job of AAEC Chief Scientist**.** With the commissioning of HIFAR he became perhaps the only person to be involved in the design, construction and commissioning of the first nuclear reactors in three countries – Canada, the United Kingdom, and Australia. His appointments in those three cases, and the highly successful outcomes, are a testimony to his scientific and technological ability and to his extraordinarily high administrative and management ability.

After taking up appointment at the University of Sydney in 1960, Charles expended great enthusiasm and energy building up his research group, the W. D. and H. O. Wills Plasma Physics Department, one of five departments, established by Prof. Harry Messel in the late fifties. He spent a year at the University of California, Berkeley to familiarise himself with some of the science and technology of the field. He returned at the end of 1960 and introduced a method of plasma preparation for the Sydney experiments that had begun to be studied at Berkeley.

A measure of the subsequent success and standing of Charles and his group was that he was chosen as one of only four people to present invited papers on the state of controlled thermonuclear research worldwide at the Third Atoms for Peace Conference in Geneva. The group was also well known for the very high quality of its graduates, the majority of whom went overseas for post-doctoral experience, in most cases to major laboratories where they were highly regarded.

Towards the end of his career Charles developed an interest in other energy sources, particularly solar energy. He was the prime mover behind the successful work on solar energy that led to the formation of the Department of Applied Physics within the School of Physics. His involvement with solar energy research and with broader aspects of energy research continued for a few years after his retirement through his appointment as Energy Consultant to the Science Foundation for Physics at the University from 1981-1985.

Degrees and honours

- DSc (Victoria University, New Zealand, 1968).
- OBE (1946).
- Fellow, Institute of Physics (London).
- Fellow, Australian Institute of Physics.

- Fellow, Institution of Engineering (Australia).
- Fellow, Australian Academy of Science (1968). [9] §

[9] M.H. Brennan: http://www.science.org.au/academy/memoirs/watson-munro.htm